PRESENT STATUS OF UVSOR-II FEL

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Abstract

For user experiments, the long term stability of output power of UVSOR-II FEL is increased by two treatments. Rapid degradation of FEL power due to cavity mirror deformation was compensated by a feedback control of the mirror angles. Rather slow power degradation due to beam current decrement was cancelled by the top-up operation of the storage ring. The feedback control allowed us to maintain the FEL power almost constant for 20 minutes. And we succeeded in keeping the FEL power constant for 90 minutes with the top-up operation. Now several new experiments and upgrade of storage ring is being planned.

INTRODUCTION

On the UVSOR storage ring, a free electron laser (FEL) has been developed as a new light source since early 1990s. In 1996, a helical optical klystron was installed and the performance of the FEL was improved much because of a smaller degradation of cavity mirrors and a higher FEL gain. Then the shortest wavelength (239 nm) of the storage ring FEL at that time was achieved [1]. After recent upgrade, FEL lasing around 199 nm has been achieved [2]. The main parameters of UVSOR-II FEL are listed in Table 1. Now the UVSOR-II FEL is proceeding to the application phase. Several user experiments [3, 4, 5, 6, 7] have been carried out in various spectral regimes.

Good long term stability of laser power is strongly required for user applications. However, the stability of UVSOR-II FEL is not sufficiently good. Two considerable reasons exist; one is cavity mirror deformation due to heavy heat load by the synchrotron radiation and FEL light, and the other is short stored beam lifetime (< 1 hour) at the single or two-bunch operation due to Touscheck effect. Therefore we made two efforts to overcome those difficulties; one is feedback control of the cavity mirror, and the other is top-up operation of the storage ring with FEL mode. Results of those studies are reported in this paper. And future prospects of UVSOR-II FEL are also described.

FEEDBACK COMPENSATION OF CAVITY MIRROR DEFORMATION

Due to heavy heat load on FEL cavity mirrors caused by synchrotron radiation and FEL light, deformation of the cavity mirror rapidly occurs at the starting time of irradiation of those radiations. The deformation leads to misalignment of the optical cavity and degradation of FEL power. Figure 1 shows temporal evolution of laser power. As one can see in the figure, we are required to adjust the mirror angles so frequently in order to maintain the FEL power.

Table 1: Main parameters of UVSOR-II FEL

Storage Ring	
Energy	600 MeV or 750 MeV
Circumference	53.2 m
RF Frequency	90.1048 MHz
Harmonic Number	16
Max. Beam Current for FEL	~ 100 mA/bunch
Optical Klystron	
Structure	APPLE-II
Number of Periods	9 + 9
Period Length	110 mm
Length of Dispersive Section	302.5 mm
K-value	0.07 – 4.6 (Helical) 0.15 – 8.5 (Linear)
Optical Cavity	
Cavity Length	13.3 m
Mirror	HfO_2, Ta_2O_5, Al_2O_3 multi-layer
FEL Performance	
Wavelength	199 – 800 nm
Pulse Rate	11.26 MHz CW
Spectral Width	~ 10^{-4}

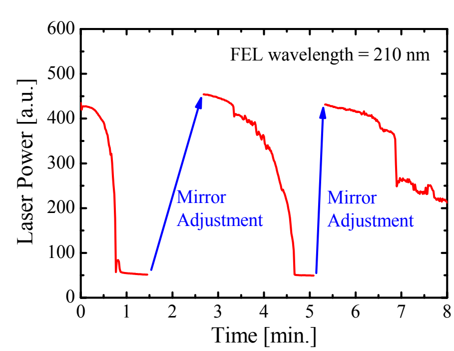

Figure 1: Temporal evolution of FEL power with manual mirror adjustment.

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Evaluation of Cavity Mirror Deformation

At the beginning of this study, the deformation of mirror with irradiating the synchrotron radiation was measured with observing reflected laser from the cavity mirror as shown in Fig. 2. Result of measurement is shown in Fig. 3. The angle of reflected laser rapidly changed just after starting irradiation. And 10 minutes later, speed of the angle change was slowed down. The slow mirror deformation was probably caused by slow decrement of heat load induced by synchrotron radiation due to slow decrement of the stored beam current.

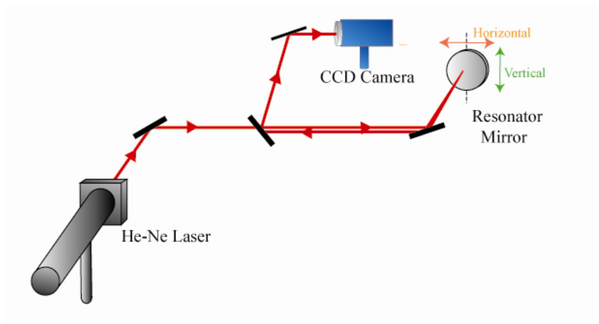

Figure 2: Measurement set-up of mirror deformation.

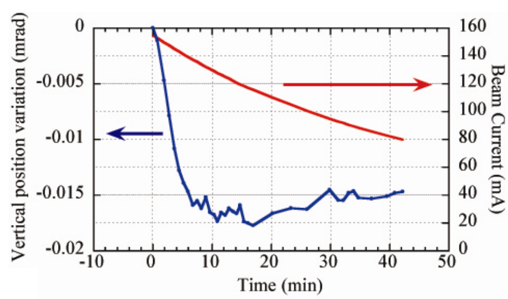

Figure 3: Measured variation of reflected laser angle. SR irradiation was started at 0 min.

Feedback Compensation of Mirror Deformation

To mitigate the mirror deformation, we introduced a feedback system shown in Fig. 4. First, transmitted FEL power through a cavity mirror is measured by a photodiode and is send to a personal computer. Then the software on the personal computer decides the direction of a mirror to change. The principle of changing the mirror angle is based on comparison of FEL power before and after the change of the mirror angle. If the FEL power after changing the mirror angle is higher than one before changing it, the software decides to change the mirror angle to the same direction again, and vice versa. Finally, the software transfers the determined value to a stepping motor controller, and the mirror angle is changed by the stepping motor. This routine action is made every 2 seconds and it controls upstream and downstream mirrors.

Figure 5 shows results of lasing experiment with and without the feedback control. The long term stability of FEL power was obviously improved with the feedback control. However effect of decreasing beam current on FEL power could not be compensated by the feedback control. The top-up operation of the storage ring is only the solution of the problem.

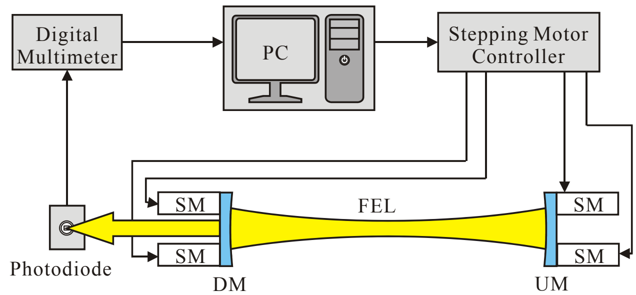

Figure 4: Schematic image of cavity feedback system. SM : Stepping Motor. DM : Downstream Mirror. UM : Upstream Mirror.

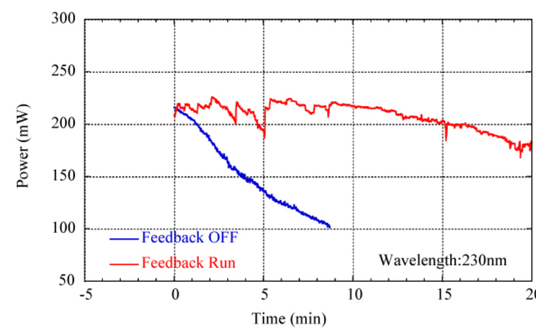

Figure 5: Results of lasing experiment with and without feedback control of mirror cavity.

TOP-UP OPERATION OF UVSOR-II FEL

For lasing of UVSOR-II FEL, the stored beam current in the storage ring should be larger than several tens of milliamps with two-bunch filling. Lifetime of the stored beam in UVSOR-II storage ring is usually shorter than one hour with the lasing condition. And then, lifetime of FEL is shorter than half hour, so that electron beam injection should be done so frequently. It is really time-consuming and inconvenient for users and operators. To solve the problem, the top-up operation with FEL mode is required. And the top-up operation requires upgrade of injector of UVSOR-II for single bunch injection because of radiation restriction of the facility. In this section, details of the injector upgrade and top-up operation of UVSOR-II FEL are reported.

Single Bunch Injection

The UVSOR-II injector consists of a DC gun, a travelling-wave type linac and a 750 MeV booster synchrotron. And the injector only can injects 4 bunches into the storage ring. The two-bunch mode is realized by eliminating redundant 3 bunches using an RF knockout [8]. Then the charge loss in the storage ring is large, and then the radiation dose at the user station is too large to enter there. Therefore, we upgraded the injector as it can inject single bunch into the ring to reduce the radiation dose dramatically.

Because of the low RF frequency (90.1 MHz) of the storage ring and booster synchrotron, the single bunch injection for UVSOR-II is not so difficult if the linac can provide electron beams having shorter macro-pulse duration than the RF bucket width (~11 ns). The timing diagram is shown in Fig. 6. A short pulse electron beam is generated at the linac, and injected to only a single bucket. When the proper injection phase of the 90.1 MHz RF is selected, the electron beam can be accelerated up to 750 MeV without dropping into other buckets. The DC gun is equipped with two grid pulsers; one is for long pulse operation (2 μs), and the other is for short pulse operation (5 ns). For single bunch operation, the grid pulser for short pulse operation is used and electron beams having 5 ns macro-pulse duration were successfully generated.

Figure 7 shows the injection rate and stored current with the single bunch injection. The injection rate of around 0.1 mA/sec was achieved. The bunch purity was measured and it was confirmed that the enough purity for FEL operation is achievable.

For FEL operation, two-bunch mode with equal bunch spacing is required. Therefore, the timing of the injector operation is changed shot-by-shot to distribute electrons to two buckets with equal spacing.

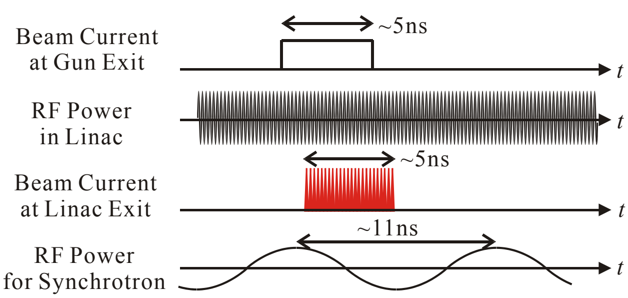

Figure 6: Timing diagram of the single bunch injection.

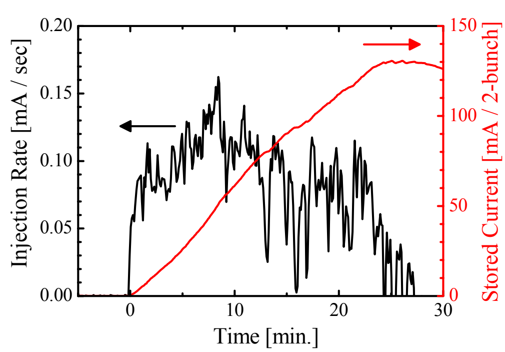

Figure 7: Temporal evolution of the injection rate and stored beam current with single bunch operation scheme.

Demonstration of Top-up Operation

Top-up operation of UVSOR-II FEL was demonstrated. The FEL wavelength and polarization were 215 nm and circular polarization, respectively. And the electron beam energy was 750 MeV. The feedback system of FEL cavity mirrors was turned off in the experiment. As shown in Fig. 8, the stored beam current in the storage ring was kept constant around 130 mA with 2-bunch mode for 90 minutes. The FEL average power was kept constant around 115 mW without cavity mirror adjustment.

Although the effect of electron beam injection on the lasing process is not clarified, it was demonstrated that the top-up operation can solve the problem of short electron beam lifetime in UVSOR-II FEL.

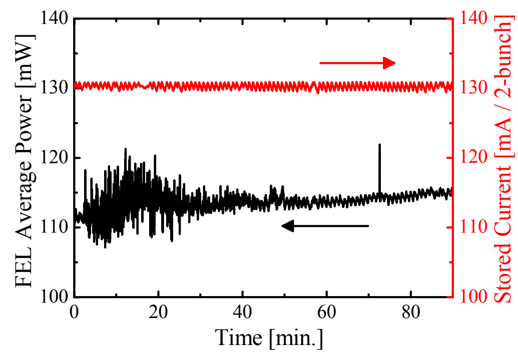

Figure 8: Result of top-up operation of UVSOR-II FEL.

FUTURE PROSPECTS

Now the shortest wavelength of UVSOR-II FEL is 199 nm [2]. We are now planning to carry out lasing experiment at the wavelength of 193 nm. We have already purchased a pair of multilayer dielectric mirror, which has higher reflectivity (> 97%) at the target wavelength.

An in-vacuum Vacuum Ultra Violet (VUV) spectrometer has been installed at the downstream of the FEL cavity mirror [9]. The spectrometer will allow us to make lasing experiment at VUV region. For that experiment, we are now looking for a company can provide multilayer mirrors, which has high reflectivity at the region.

Now the optical klystron (U5 in the Fig. 10) is shared with SR users, so that we could not make experiments during user operation time. In next fiscal year, the UVSOR-II storage ring will be upgraded as shown in Fig. 10. By rearranging the injection point and the main RF cavity of the ring, one long straight section will be available for installing an undulator. And at the section, a new optical klystron, which is dedicated to the development of advanced light sources such as FEL, Coherent Synchrotron Radiation (CSR) [10, 11] and Coherent Harmonic Generation (CHG) [9]. The FEL optical resonator will be also rearranged. The upgrades will accelerate the development of the advanced light sources at UVSOR facility.

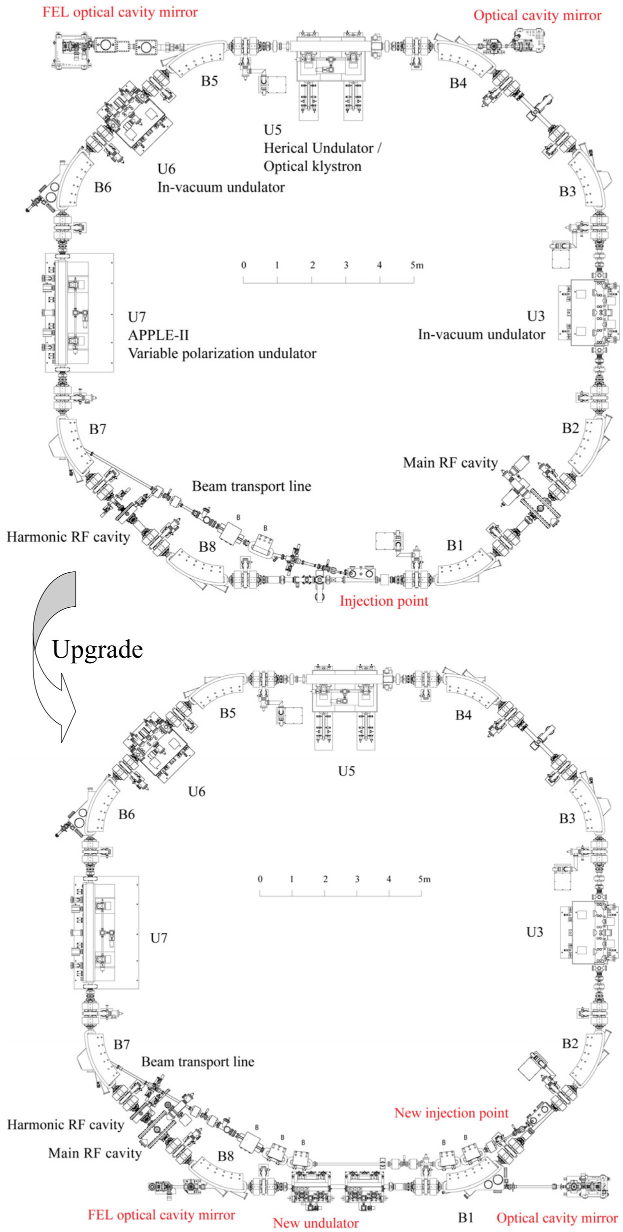

Figure 10: Upgrade plan of UVSOR-II storage ring. Now (upper figure) U5 is used for FEL experiment and shared with SR users. In the upgrade plan (lower figure), new dedicated undulator to the advanced light source development will be installed.

SUMMARY

The long term stability of UVSOR-II FEL was increased by the feedback control of cavity mirrors and top-up operation of the storage ring. We succeeded in maintaining the FEL power for 20 minutes by the feedback control and for 90 minutes by the top-up operation. Although the effect of beam injection is not clarified, it was demonstrated that the top-up operation can solve the short electron beam lifetime problem of UVSOR-II FEL.

As the next step, trial on lasing at 193 nm will be carried out. And lasing experiment at VUV region is also being planned.

In next fiscal year, the UVSOR-II storage ring will be upgraded and a new optical klystron, which is dedicated to the advanced light source development such as FEL, CSR and CHG, will be introduced. This upgrade will accelerate the advanced light source development in UVSOR facility.

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